CHAPTER 4

ENVIRONMENTAL RESOURCES

Prior to human development in the state of Florida, the hydrology of Lake Okeechobee was coupled directly to that of the meandering Kissimmee River and its marsh ecosystem in the northwest, and to the great expanse of Everglades marsh in the south (Figure 18). During periods of high rainfall, water exited the lake at its south end as a broad sheetflow into the Everglades ecosystem. Today the lake is entirely surrounded by an earthen dike as part of the C&SF Project and disconnected from the Everglades marsh. Water levels in the lake (lake stage) now are much lower than under natural conditions (see Chapter 5), and a marsh zone occupies about 25% of the lake's surface area along the southern and western shores in a region that was once under water.

Two major efforts launched by the SFWMD and USACE (the Lake Okeechobee Regulation Schedule Study (LORSS) and the C&SF Restudy Project) are designed to restore as much of the natural system as possible, while meeting the water supply demands of a growing human population in South Florida. The Lake Okeechobee regulation schedule being developed (see LORSS in Chapter 5) should benefit the estuaries, the lake's marsh zone, and the Everglades. Some of the key projects described in this chapter relate to these efforts, in particular the research that has occurred or is planned to provide necessary information on how water supplied from Lake Okeechobee will effect the marsh zone inside the lake.

Usually after prolonged periods of heavy rainfall, the stage in Lake Okeechobee can rise above the maximum set by the Lake Okeechobee regulation schedule (see Chapter 5), forcing discharges to the St. Lucie and Caloosahatchee estuaries on the east and west coast, respectively, of Florida. In addition, local watershed runoff has been augmented by the drainage system that has been constructed for agriculture and urban development. As a result, these estuarine ecosystems periodically experienced unnaturally large inputs of freshwater that have devastating impacts on the estuarine fish, shellfish, plants, and other biota.

In addition to hydrological and morphological modifications, the lake has been impacted by nutrient overloading (described in Chapter 3). Excessive inputs of phosphorus and nitrogen from agricultural operations located to the north and south of Lake Okeechobee have led to increases in lake water nutrient concentrations, more frequent algal blooms, and dominance by algal and animal species that are tolerant of eutrophic conditions (Havens *et al.* 1996a). These trends, and their possible reversal due to management programs, have the potential to dramatically affect the values of the ecosystem for humans and wildlife, and also are addressed by projects in this chapter.

Figure 18. Historic and modern flows associated with Lake Okeechobee.

A third human-related impact suffered by the lake in the latter part of this century is the introduction and proliferation of exotic plants in the marsh and submerged aquatic zones. These plants include *Melaleuca*, torpedo grass, Brazilian pepper, *Hydrilla*, water hyacinth and water lettuce. Management efforts to control certain exotic plants in the lake have recently been linked with research projects, in order to develop methods to control expansion of the exotic plants, and also are addressed in this chapter.

The following provides a summary of major challenges and strategies derived from the materials contained within this chapter.

Challenge: High water levels may have an adverse affect on plant and animal communities. Data are lacking on the relationship between lake stage and community response. (also part of the Flood Control/Water Supply Chapter)

Strategy: Conduct research to quantify lake stage effects on marsh community structure and function, including nutrient cycling and physiology, germination, spatial distribution, and competition between native and exotic plants. Evaluate how changes in plant communities may impact fish, wildlife, and other ecological and societal values of the ecosystem.

Challenge: External and internal nutrient inputs may have adverse environmental effects for the in-lake and the downstream regional ecosystems. Information is lacking on the relationship between nutrients and community response.

Strategy: Quantify the extent to which key biological process are affected by nutrients and predict community response to different management scenarios through modeling. Evaluate how different management scenarios, including those considered in the C&SF Restudy, will impact the nutrient content of water flowing from the lake to the EAA, Everglades Protection Area, and estuaries.

Challenge: Exotic plants, both *Melaleuca* and Torpedo grass, have replaced entire native plants communities, possibly lowering fish and wildlife habitat quality.

Strategy: Continue the *Melaleuca* herbicide control program and implement biological controls. Continue research for optimizing herbicide treatment of Torpedo grass.

A. GOALS, OBJECTIVES AND STRATEGIES

The overall goal is to protect and enhance the environmental resources of Lake Okeechobee, and enhance the lake's functional role in the regional aquatic ecosystem. In order to protect and enhance the lake ecosystem, it is necessary that the following should be implemented: (1) experimental and process-oriented research to quantify

key ecosystem processes and relations between ecosystem health and environmental forcing functions, such as lake stage, rainfall, and nutrient loading; (2) development and use of predictive models to guide decision makers in selecting optimal management actions to enhance the ecosystem; and, (3) long-term monitoring of selected ecosystem attributes, including physical, chemical, and biological ones. This last activity is essential to assess how the lake responds to management actions, and to detect harmful trends before they progress to such an extent that the system is irreversibly damaged.

Superscript notation indicates projects that are in the proposed budget (Chapter 9).

Goal 1: Protect and enhance the environmental resources of Lake Okeechobee, in terms of their biological diversity, ecological functions, and spatial distributions.

> **Objective 1:** Develop a predictive understanding of how different lake stages affect the lake's environmental resources.
>
> > **Strategy 1**: Quantify relationships between lake stage and the germination, growth, and spatial distribution of native and exotic plant communities.[15,16,27,28]
> >
> > **Strategy 2:** Quantify wildlife utilization of different plant communities, both native and exotic, to the extent that we may predict how different lake regulation schedules would affect fish, wading birds, and other important animals.[13,27,28]
> >
> > **Strategy 3:** Develop minimum and maximum environmental water level criteria in order to prevent irreversible harm to the lake ecosystem.
> >
> > **Strategy 4:** As part of the Lake Okeechobee Regulation Schedule Study, develop and refine performance measures needed to select the best alternative that protects and enhance the environmental resources of the Lake Okeechobee marsh and submerged aquatic plant zones.
> >
> > **Strategy 5:** As part of the C&SF Restudy effort, ensure that project scenarios consider impacts of modified regional water delivery systems on the lake's biota.
>
> **Objective 2:** Develop a predictive understanding of how external and internal nutrient inputs affect the lake's environmental resources.
>
> > **Strategy 1:** Quantify biological processes that control phosphorus and nitrogen cycling in the lake.[18]

Strategy 2: Quantify experimentally how open-water and marsh zone communities would be impacted by varied inputs of phosphorus and/or nitrogen.[14]

Strategy 3: Quantify the lake's food web so that predictions can be made regarding how fish, wading birds, and other animals respond to changes in nutrient input at the bottom of the food web.[17,19]

Strategy 4: Continue to refine the lake's hydrodynamic and water quality models so that predictions of lake response to management actions can be made with the lowest practical uncertainty.[11,12]

Objective 3: Determine the factors that regulate expansion of exotic plants in the lake's marsh zone, and identify optimal methods for eradicating exotic plants from the lake.

Strategy 1: Quantify the spatial distribution of exotic plants in the lake's marsh zone.[20,22,27,28]

Strategy 2: Identify optimal strategies for the control of exotic plants.[21]

Strategy 3: Continue and refine ongoing programs of exotic plant control.[23]

Objective 4: Quantify long-term trends in the lake's environmental resources, including fisheries, threatened or endangered species, wading birds, native and exotic plant communities, algae, and invertebrates.

Strategy 1: Develop and implement a program of long-term ecological monitoring, in order to quantify temporal trends in key ecological attributes, and compile the diverse data into a common data repository.[24,25,26,27,28]

Goal 2: Enhance the functional role of Lake Okeechobee in the regional aquatic ecosystem.

Objective 1: Identify, protect, and enhance critical habitats or areas to protect sensitive communities and/or rare, threatened, or endangered species.

Strategy 1: Coordinate efforts on the management and protection of rare, threatened, or endangered species with the USFWS, FGFWFC, and other state and federal agencies.

Strategy 2: Continue activities under the Kissimmee River Restoration Project.

Objective 2: Minimize environmental impacts to estuaries resulting from changes in the quantity, quality, or timing of freshwater releases from the lake.

> **Strategy 1:** Quantify impacts of freshwater discharges from the lake on the biota of the Caloosahatchee and St. Lucie estuaries, and establish an optimum range of fresh water inflows.

> **Strategy 2:** Quantify impacts of nutrients and critical material loading to the estuaries from the lake and establish optimal loading ranges.

> **Strategy 3:** As part of the Lake Okeechobee Regulation Schedule Study, develop and refine performance measures needed to select the best alternative that protects and enhance the environmental resources of the Caloosahatchee and St. Lucie estuaries.

> **Strategy 4:** As part of the C&SF Restudy effort, ensure that project scenarios consider impacts of modified lake water regulation schedules and construction projects on the estuarine biota.

B. ECOLOGICAL IMPACTS OF LAKE STAGE VARIATION

The marsh zone is vital to a variety of animals, and is utilized for spawning by fish (Fox *et al.* 1993), as nesting and feeding areas by wading birds (Smith and Callopy 1995, Smith *et al.* 1995), and is a habitat for threatened and endangered species like the snail kite. Lake stage currently displays considerably more variation than before dike construction (Figure 19). Because the marsh zone is constrained to a region inside the dike, such variations in lake stage cause complete exposure or submersion of this community (Figure 20). Although marsh zone biota are normally adapted to extreme conditions of wet and dry, the long-term unnatural flooding, i.e., for more than two consecutive years, can have deleterious impacts on plants, fish, birds, and other wildlife.

B1. Lake Stage Effects on the Marsh Zone Community

The vegetation in the marsh zone of Lake Okeechobee has been studied on several occasions during the past 35 years (e.g., Sincock 1957, Pesnell and Brown 1977, Richardson *et al.* 1995), and the results indicate that hydroperiod is the primary factor determining plant community structure. In 1981, following several years of prolonged high lake stages, vegetation was sampled along a transect in the Indian Prairie region, where data also had been collected in 1973. Milleson (1987) reported the native spikerush (*Eleocharis cellulosa*) had been eliminated, while torpedo grass, an invasive exotic, had increased in dominance, and cattail also had expanded. Torpedo grass is a particularly troublesome invader because is can adapt to both low and high lake stages. Low water conditions in 1981 and 1982 seemed to reverse some

Figure 19.   Annual fluctuation in Lake Okeechobee stage. Average value is the middle, thick line.

Figure 20. Marsh zone coverage at six water levels. The darker shaded area represents land that is exposed at these lake stages. When stage is 15 ft. NGVD or higher, nearly 100% of the marsh zone is submerged, and when lake stages are at 11 ft. NGVD or lower, nearly 100% of the marsh zone is exposed.

of the trends, as sampling in 1982 indicated little overall change from 1973 conditions. Milleson concluded that prolonged inundation could reduce or eliminate species which require occasional drying, such as spikerush, and encourage more flood-tolerant species, such as cattail.

For the LORSS, performance measures have been developed, through a multi-agency effort, that allow for relative comparisons between alternative lake regulations schedules. Output from the South Florida Water Management Model will be analyzed to rank these alternatives. The model provides hydrologic information on the quantity, depth, frequency and duration for Lake Okeechobee, the Caloosahatchee and St. Lucie estuaries, and the Everglades.   Following are the performance measures that have been developed for the marsh zone, with the principal objective of protecting and improving aquatic and wildlife habitat.

Performance Measure No. 1 - *Similarity in Stages.*

The stage (median depth, 25 and 75 percentile break-points) of each alternative will be compared to the period of historical record (1950-1972). Alternatives which have the greatest degree of similarity with the historical record will be ranked as better.

Outputs to be analyzed include: a whisker box plot type analysis of lake stage

Rationale: The marsh community that developed during the 1953-1972 time period most closely resembles the "desired" condition for this portion of Lake Okeechobee, according best professional judgement (multi-agency effort including USACE, USFWS, FGFWFC, FDEP, and the SFWMD). The fluctuation in lake stage during this time period is assumed to have led to the development of this community. The alternatives that have stages that are most similar to this historical record should sustain or rejuvenate these marsh communities.

Performance Measure No. 2 - *Similarity in Flooding Duration*

The duration (median length of time, 25 and 75 percentile break-points) for each lake stage event over 15 ft. NGVD for each alternative will be compared to the period of historical record (1950-1972). Alternatives which have the greatest degree of similarity with the historical record will be ranked as better.

Outputs to be analyzed include: a whisker box plot type analysis of lake stage duration above 15 ft. NGVD

Rationale: The marsh zone in Lake Okeechobee that developed, as a result of the Herbert Hoover Dike system, is constrained to areas inside the dike. During periods of abundant rainfall, the marsh may become completely inundated, which starts when lake stage reaches 15 ft. NGVD. Occasional inundation is part of the normal

cycle for marsh plants. However, if the marsh experiences prolonged high lake stages, certain vegetative communities suffer ecological harm, including willow habitat, and submerged aquatic vegetation. In addition, fish & wildlife associated with these habitats are also harmed. By optimizing the duration that the lake remains above 15 ft. NGVD, ecological harm caused by prolonged high water may be reduced, and the benefits of occasional high water are sustained.

Performance Measure No. 3 - *Number, Duration and Frequency of Return of Periodic Lower Lake Stages*

The number of lake stage events below 12 ft. NGVD during the dry season for no more and no less than every 3 years, and no more than 120 days and no less than 90 days, will be compared for each alternative. Alternatives which meet this periodic low lake stage will be ranked as better. The number of lake stage events below 11 ft. NGVD during the dry season for no more and no less than every 7 years, and no more than 120 days and no less than 90 days, will be compared for each alternative. Alternatives which meet this periodic low lake stage will be ranked as better.

Outputs to be analyzed include: (1) a whisker box plot type analysis of lake stage duration below 12 ft. NGVD; (2) below 11 ft. NGVD; (3) analysis of frequency of return below 12 ft. NGVD (for 90-120 days); and (4) below 11 ft. NGVD (for 90-120 days).

Rationale: Periodic short-term drying of the marsh ecosystem may ensure the health of willow nesting habitat, encourage the development of successional complexes of vegetation that attract a variety of bird life for foraging, encourage nutrient recycling, and allow fires to clear thick and unproductive cattail and torpedo grass.

Performance Measure No. 4: - *Moderate Lake Stage Recession*

The moderate recession of lake stage to below 14.0 ft. NGVD during the period from January to May with no reversal greater than 0.5 ft. over a 15 day period. The optimal alternative shall be judged as the one in which the maximum number of years display this pattern.

Outputs to be analyzed include: Stage hydrographs

Rationale: A gradual recession in lake stage, coincident with the wading bird breeding season, has reduced nest flooding, and concentrates prey organisms in submerged aquatic vegetation, canals, and air boat trails within the marsh zone. Moreover, the highest wading bird foraging activities, highest nesting activity among most species, and highest per nest productivity among all wading birds, were associated with a gradually declining lake stage.

There remain unanswered questions regarding hydroperiod and its influence on

exotic versus native plant competition, seed germination, and vegetative reproduction. At present, the best information exists for *Melaleuca*, whose germination and growth has been simulated for a variety of lake stages and hydroperiods (Lockhart 1995). Experimental results indicate that low lake stages, which expose marsh zone soils, may favor the germination of *Melaleuca* seeds. Once established, young plants can grow rapidly under exposed or flooded conditions. Similar information is needed for other species of exotic and native plants. Additionally, the potential for re-establishment of native plant communities in areas which have been lost to exotic invasion needs to be evaluated, including studies to elucidate the impacts of hydroperiod on restored sites. Future research efforts in this area should include: studies to determine the viability of native seed banks within exotic-dominated areas of the marsh zone; controlled experiments to determine how hydroperiod and lake stage affect germination, and growth rates of all major exotic and native plants; and experimental, large-scale competition studies between selected species of native and exotic plants under varying hydroperiods.

B2. Wildlife Utilization of Native and Exotic Plant Communities

Hundreds of species of animals including birds, fish, mammals, amphibians, reptiles, and invertebrates utilize the more than 70 species of vascular plants and plant communities found in Lake Okeechobee's marsh zone for nesting, foraging, feeding, and shelter (Aumen and Wetzel 1995, Havens *et al.* 1996b). Collectively, the wildlife associated with the lake's marsh zone comprises a complex and valuable animal community. Because exotic vegetation has rapidly expanded throughout many areas of the marsh zone, especially during the past 25 years, there is concern that the loss of thousands of hectares of native plant communities has degraded the habitat quality of the ecosystem. However, there are limited quantitative data to support this view. In order to protect and enhance valuable wildlife habitat, a thorough evaluation of wildlife species diversity and habitat use of both exotic and native plant communities should be conducted. As part of the Lake Okeechobee Ecosystem Study, wading bird use of distinct vegetation types was considered, and it was documented that certain native vegetation types (e.g., willow) offer optimal nesting or foraging habitat (Smith and Callopy 1995, Smith *et al.* 1995). Other animal groups were not considered. In a recent study, scientists at the FGFWFC documented that *Hydrilla, Potamogeton*, *Vallisneria*, *Scirpus,* and *Nymphaea* provide good habitat for recreational fish (Furse and Fox 1996).

Recognizing the need for a holistic study of wildlife utilization in various native and exotic plant communities, the SFWMD, FGFWFC, and USACE recently have proposed a multi-agency effort to conduct a multi-year study in selected areas of the lake's marsh and submerged aquatic plant zones. The SFWMD currently is working on the creation of a detailed GIS vegetation data base and vegetation map of the lake's 40,000 ha marsh zone. Initial efforts are proposed to focus on the following vegetation types: *Eleocharis*, willow, torpedo grass, brazilian pepper, *Melaleuca*, and multiple submerged multiple species. Subsequent studies, considering additional

components of the native plant community, could result in animal data layers that could be viewed in a GIS framework along with the underlying vegetation distribution. Ultimately, this sort of information might be used in efforts to model ecosystem-level responses to management actions, such as changes in lake regulation schedules.

B3. Minimum Water Level Criteria

To ensure that modifications of the Lake Okeechobee water regulation schedule and/or additional water demands on the lake do not cause significant harm (defined here as an adverse change that is not readily recoverable) to the ecosystem, SFWMD staff have recently developed guidelines for minimum water levels. Details may be found in the SFWMD's Planning Department document entitled "Minimum Water Flows and Levels Criteria in the Lower East Coast Planning Area of South Florida." In overview, scientists considered three sources of information: (1) results from the Lake Okeechobee Ecosystem Study (Aumen and Wetzel 1995); (2) historic information on lake stages and vegetation community structure; and, (3) Geographic Information Systems information on percent of marsh zone inundation at various lake stages and published information on hydrologic optima for certain native and exotic plants. Based on the results, it was concluded that a healthy marsh zone community requires a variable lake stage, with yearly highs above 15 ft. NGVD and lows below 13 ft. NGVD, and drawdowns to below 11 ft. NGVD occurring about once every 7 years. Prolonged or more frequent drawdowns were concluded to be deleterious, because they increase the probability for exotic plant expansion and large-scale fires. The following minimum lake stage criteria were developed:

1. *Minimum Levels and Return Frequency*: Lake stage should not fall below 12 ft. NGVD more often than one time every three years, and not below 11 ft. NGVD more often than one time every seven years.

2. *Duration Criteria*: Lake stage should not remain below these designated criteria for longer than 120 days per event.

It is recognized that these criteria are based on currently available information (which is relatively sparse), and that additional research is needed to validate the criteria and certain assumptions on which they are based.

B4. Central and Southern Florida (C&SF) Project Comprehensive Review

The C&SF Project is a multi-purpose project of the USACE, that was first authorized in 1948 to provide flood control, water control, water supply, and other services to the area that extends from Orlando to Florida Bay. The purpose of the C&SF Project Comprehensive Review is to reexamine the C&SF Project to determine the feasibility of modifying the project to improve the sustainability of South Florida. Specifically, as required by the authorizing legislation, the review will investigate

making structural or operational modifications to the C&SF Project to improve the quality of the regional environment, improve protection of the aquifer, improve the integrity, capability, and conservation of urban and agricultural water supplies, and improve other water-related purposes. Several alternatives will be developed into a plan that can be implemented over the next several years. As a part of this project, SFWMD and USACE staff will consider carefully the potential environmental impacts on Lake Okeechobee as a result of the potential changes in the system. To a large extent, the affect of alternative plans will be based on modeling and data from the Lake Okeechobee Ecosystem Study, however, additional research is needed to better quantify impacts of lake stage on the marsh zone.

C. ECOLOGICAL IMPACTS OF NUTRIENTS

The biological communities of Lake Okeechobee have been dramatically impacted by the excessive inputs of phosphorus and nitrogen (see Chapter 3). Typical symptoms of cultural eutrophication, summarized in Havens *et al.* (1996a), have been observed in the lake (Figure 21), including: (1) a shift in the composition of benthic macroinvertebrates toward more pollution-tolerant species (Warren *et al.* 1995); (2) an increase in the biomass of blue-green algae relative to other, more desirable, algal groups (Cichra *et al.* 1995); and, (3) an increase in chlorophyll *a* concentrations (Havens *et al.* 1995). The lake's sediments have accumulated large quantities of phosphorus (over 28,000 metric tons in the surface sediments alone), and sediment-to-water column phosphorus fluxes now equals the external phosphorus inputs on an annual basis (Olila and Reddy 1993).

Because dissolved phosphorus concentrations often exceed the requirements of the algae, growth rates generally are limited by other factors, in particular light and nitrogen (Aldridge *et al.* 1995). A high frequency of nitrogen limitation, relative to phosphorus, favors dominance by nitrogen-fixing blue-green algae, including species that form surface blooms (Reynolds 1993).

Considerable efforts have been made to reduce the external nutrient inputs to Lake Okeechobee (as described in Chapter 3), and managers continue to explore new approaches for further reductions of phosphorus and nitrogen loads, both external and internal to the lake ecosystem. Management actions can often have dramatic economic and ecological impacts (Havens *et al.* 1996a), and it is critical that these actions are based on sound scientific information about the ecosystem and its expected responses. Information now exists regarding certain ecosystem properties, such as phosphorus geochemistry in the limnetic (open water) region (Reddy *et al.* 1995), while other key areas are largely unexplored.

C1. Biological Processes Controlling Nutrient Cycling

There is evidence from the recently completed Lake Okeechobee Phosphorus

Figure 21.   Lake benthic invertebrates and phytoplankton. Documented historical changes in the composition of benthic invertebrates (CHIRO = chironomids, OLIGO = oligochaetes) and phytoplankton (EUGLE = euglenophytes, DINOF = dinoflagellates, CRYPTO = cryptophytes, DIATOM = diatoms, CHLORO = chlorophytes, CYANO = cyanophytes), indicating a shift towards more pollution-tolerant species (from Havens *et al.* 1996a).

Dynamics Study (Reddy *et al.* 1995), as well as from other research projects conducted on this and other shallow eutrophic lakes, that biological interactions play an important role in the internal cycling of phosphorus. These interactions include, but are not limited to: (1) competition for dissolved phosphorus by benthic plants, benthic algae, and planktonic algae in shallow regions near the marsh edge; (2) suppression of wind-driven sediment-associated phosphorus resuspension by benthic plant assemblages in those same lake regions; (3) bioturbation of lake sediments by benthivorous fish and benthic macroinvertebrates; and, (4) vertical migration by bloom-forming blue-green algae.

Both observational (Scheffer *et al.* 1994) and experimental (Confer 1972, Hansson 1990) studies have revealed competitive interactions between benthic and planktonic communities. In Lake Okeechobee, Phlips *et al.* (1993a) documented that a midsummer low in phytoplankton biomass corresponded with maximal biomass of epiphyton and submerged plants. Havens *et al.* (1996c) reported that both benthic and planktonic algae were limited by similar nutrients, confirming the potential for nutrient competition. Currently, a study is ongoing that examines the uptake and release of both inorganic and organic phosphorus among the benthic algae, phytoplankton, and bacterioplankton communities at four sites in Lake Okeechobee. Three of these sites are located at the interface between marsh and limnetic regions of the lake, where the potential for competition between benthic and planktonic organisms is strongest. The fourth site is located deep within the marsh zone in a pristine, nutrient-poor area. Sampling will take place bi-monthly over a 13-month period. This research will provide critical information on the spatial and temporal variation of phosphorus flux into different biotic compartments, which communities will be at a competitive advantage for phosphorus, and whether or not this competitive advantage varies with season.

The large reservoir of phosphorus stored in the sediments of Lake Okeechobee can serve as a net source of phosphorus to the water column via phosphorus desorption from resuspended sediments or diffusive flux (Olila and Reddy 1993). In situations where the sediments act as a phosphorus source to the water column, benthic plants have the capability to reduce sediment resuspension (and phosphorus flux to the water) because their rooting structures may physically bind sediments and their morphology may present a physical barrier to lateral shear forces along the benthos. In cases where diffusive flux is important, benthic plants may assimilate released inorganic phosphorus, thereby preventing increases in water column phosphorus concentrations. In the southern part of Lake Okeechobee, extensive "lawns" of the macroalga *Chara* can form in the summer and fall months. This plant may play an important role in nutrient cycling because of its ability to bind sediments, assimilate nutrients, and change the dissolved oxygen and pH status of the surrounding water due to photosynthesis, which in turn may influence phosphorus biogeochemistry. Research is planned that will measure the influence of *Chara* on: (1) sediment resuspension and subsequent phosphorus concentrations in the water column; and, (2) diffusive flux of nitrogen and phosphorus from the sediments.

Bioturbation by benthic invertebrates and fish is a mechanism by which nutrients can become released into overlying waters (Havens 1993). In Lake Okeechobee, Van Rees *et al.* (1996) reported that nutrient transport from sediments was 2 to 15 times greater in sediments with benthic organisms than those without benthic activity. This may be an important mechanism for liberation of soluble nitrogen and phosphorus from Lake Okeechobee sediments. The studies by Van Rees *et al.* (1996) were conducted in the laboratory on cores collected from the Lake. It is critical that field experiments also be conducted, in order to verify their applicability. Mesocosm-oriented research will allow us to pursue this topic in future years.

Vertical migration of blue-green algae, from the lake sediments to near the surface of the water column, also may be a pathway for phosphorus transport in Lake Okeechobee, as it is in other shallow lakes (Takamura *et al.* 1992). A working model of algal bloom formation in Lake Okeechobee (Havens, unpublished) suggests that during prolonged calm periods two important events occur: (1) an anoxic or hypoxic layer develops at the sediment-water interface, allowing soluble phosphorus to enter the water column where it can be taken up by blue-green algae colonies; and, (2) bloom-forming blue-green algae species (e.g., *Anabaena*), which require high light levels for optimal growth, migrate to the water surface, forming the visible surface blooms that have been such a major concern in this shallow lake. Because blue-green algae can obtain nitrogen and carbon from the atmosphere, they are essentially unlimited in their growth during such calm periods. Additional research should be done to validate this model.

Under most circumstances, planktonic algae in Lake Okeechobee appear to be more limited by nitrogen than phosphorus (Aldridge *et al.* 1995). Therefore, an understanding of nitrogen cycling is necessary for accurate predictions of algal community responses to changes in nutrient loading. In sharp contrast to the large amount of information available on phosphorus, we know very little about nitrogen dynamics in this or any other subtropical lake. Only two processes, planktonic nitrogen fixation (Phlips and Ihnat 1995) and denitrification (Messer *et al.* 1979) have been directly measured in Lake Okeechobee, the latter being studied over 15 years ago, when nutrient concentrations in the lake were much lower than at present. No studies have been conducted to measure rates of nitrification, nitrogen mineralization, or nitrogen uptake by planktonic algae, yet these processes are included in the water quality model that is used to predict algal responses to nitrogen and phosphorus load reductions. The model presently uses parameter values taken from the published literature on temperate lakes, and these rates may not be applicable for subtropical Lake Okeechobee. A pilot study in the summer of 1996 has provided information concerning planktonic algal uptake rates for nitrate, nitrite, ammonia, urea, and the various dissolved forms of this nutrient), but additional studies of a broader scale will be needed to fill this information gap.

C2. Nutrient Impacts in the Marsh Zone

Nearly all of the research to date regarding nutrient impacts has focused on the limnetic region. There now is concern that the marsh zone could be impacted by nutrient-rich water if lake regulation schedules are modified to allow higher stages during the summer wet season. When there is water exchange between the marsh and limnetic zones (most often this does not occur), the marsh zone acts as a strong sink for phosphorus (Sheng and Lee 1991, Dierberg 1992). However, it is unclear whether this function would be lost during prolonged periods of inundation. Some have suggested that the marsh zone could become a source of phosphorus (Canfield and Hoyer 1988), although this seems unlikely given the low nutrient content of marsh vegetation (Dierberg 1992, Harris *et al.* 1995).

SFWMD scientists have recently begun a series of controlled mesocosm experiments, designed to quantify the impacts of enhanced nutrient levels on the marsh zone community structure and function, including nutrient cycling. Initial studies will be conducted in a single location, the large *Eleocharis* community near Moonshine Bay, and will have a simple design (controls and nitrogen + phosphorus additions at a single level).   Subsequent experiments will be done in various community types, and will include nutrient addition gradients. The results of these studies should permit a precise estimate of how different native and exotic plant communities can be expected to respond to varying levels of phosphorus and nitrogen inputs, as well as information regarding assimilative capacity, i.e., the phosphorus and nitrogen loading rates at which the community can no longer act as a nutrient sink.

C3. Food Web Responses to Nutrient Inputs

Given the economic importance of the lake's fisheries, valued at over $100 million according to Bell (1987), it also important to predict how that resource might be impacted by changes in external and/or internal nutrient loading rates. This requires an understanding of the lake's food web so models can be developed that describe the pathways of nutrient transfer from the bottom of the web (algae, plants, and bacteria) to the top (predatory fish). At present, only a cursory understanding of how the food web is structured (Figure 22, Havens *et al.* 1996b) exists.   Some additional information will be provided by pilot studies conducted during summer and fall of 1996 using stable isotope methodology (Fry 1991, Fry *et al.* 1992), but additional studies of a larger scale will be needed to predict fisheries responses with a reasonable level of accuracy, taking into account the heterogeneous nature of the lake ecosystem.

C4. Model Development

In addition to collecting better information on input parameters, the underlying structure of lake hydrodynamic and water quality models may need to be refined in

Figure 22. Lake Okeechobee food web (from Havens *et al.* 1996b). The web appears to be very complex, with over 300 species (BIRD = wading birds, MINV = benthic macroinvertebrates, FISH = young (Y) and adult (A) fishes, ZOOP = zooplankton), and numerous feeding links (numbers associated with arrows; for example 13 bird species eat macroinvertebrates). Many parts of the food web are not yet resolved to species, including mammals (MAMM), reptiles (REPT), amphibians (AMPH), periphyton and detritus (PDMB), phytoplankton (PHYT), bacteria (BACT), flagellates (FLAG), and ciliates (CILI). Submerged macrophytes (SAV) are eaten by some macroinvertebrates, but primarily are a substrate.

order to provide solid scientific predictions to decision makers.   The SFWMD has used the WASP to develop a water quality model of Lake Okeechobee (James and Bierman 1995). Ultimate uses of this model include determining lake response times in terms of nutrient concentrations, algal biomass, and algal composition, to external nutrient load reductions.

Results from early versions of the model indicate that: (1) there is a need for a model component that explicitly considers sediment-water interactions; (2) the model should include distinct segments, corresponding to the ecological zones defined by Phlips *et al.* (1993b); and, (3) the model should include distinct algal groups (diatoms, blue-green algae, and chlorophytes). These changes were considered necessary to improve model accuracy, which was initially quite low.

A revised version of the WASP model (James *et al.* 1996) incorporates these changes. This most recent version of WASP predicts temporal variation in physical, chemical, and biological (algae) attributes with a much better accuracy (estimated as the average deviation between actual data and model output) than the simple original model.   Following validation runs, the model can be used for addressing certain management questions, such as predicting lake responses to external and internal phosphorus load reductions.

This most recent version of WASP indicates certain in-lake processes that should be studied in greater detail if the model is to be used for accurately predicting seasonal phytoplankton dynamics and bloom formation. Certain research needs have been mentioned above, but also should include: a better characterization of the composition, distribution, and dynamics of "fluid mud," a sediment layer immediately in contact with the water column that probably most influences nutrient concentrations and light availability during resuspension events; and use of the lake hydrodynamic model to estimate water flows between WASP model segments. At some point, it also may be desirable to modify the model so that vertical migration of bloom-forming blue-green algae to the water surface can be simulated under the appropriate triggering conditions.

One major goal of the modeling effort is to link watershed models, such as LOADSS (described in Chapter 3), with the in-lake water quality (WASP) and hydrodynamic models. When this is accomplished, there will be a framework for addressing the following types of management issues. (1) Given some desired in-lake condition (e.g., total phosphorus concentrations averaging 40 μg/L), WASP can be used to specify an external loading goal, and then the watershed models can be used to evaluate land use changes that might achieve that goal. Because LOADSS includes an economic component, it also may be possible to estimate impacts of the land use changes on the regional economy. (2) Given some proposed land use changes in the watershed, LOADSS can be used to estimate changes in phosphorus loading to the lake, and WASP can be used to estimate changes in water quality parameters. Ultimately, if a dynamic ecosystem model is linked with

WASP, it may be possible to estimate effects of land use changes on water quality, fish, and wildlife populations in the ecosystem. While this represents a long-term goal, scientists at the SFWMD and other state and federal agencies are now in the process of developing a conceptual ecosystem model that may serve as a starting point for the more complex dynamic model.

D. ECOLOGICAL IMPACTS OF EXOTIC PLANTS

In the marsh zone of Lake Okeechobee, at least 14 exotic plant species have been found. Of those, five species have become a major threat to the ecosystem due to their rapid expansion into areas once occupied by native plants: Melaleuca (*Melaleuca quinquenervia*) and torpedo grass (*Panicum repens*) in the higher elevation regions; water hyacinth (*Eichornia crassipes*), water lettuce (*Pistia stratiotes*), and Hydrilla (*Hydrilla verticillata*) in lower elevation areas where there is year-round standing water. There are active programs to control all of these plants except torpedo grass, and research is presently being conducted to identify optimal control strategies for that exotic (details below).

Melaleuca is an Australian tree that was first introduced into South Florida in the early 1900s. Since that time, it has rapidly invaded many natural areas in the region, creating dense monocultures which may displace native plant communities and alter wildlife value. *Melaleuca* was originally planted on the lake by the USACE in the late 1930s and early 1940s. These fast growing, fire and flood tolerant trees were installed on low-lying islands immediately lakeward of the levee to protect the levee system from wind and wave erosion. From these first plantings, *Melaleuca* now has spread to cover thousands of acres of the marsh zone in the lake.

There are two main areas of *Melaleuca* infestation at Lake Okeechobee. The first area encompasses the original plantings, along the tree islands and levee berm. Large, mature, extremely dense monocultures of *Melaleuca* cover these sites. Latest surveys of the area estimate that these monocultures occupy approximately 3,000 acres. The second main area of infestation includes the shallow marsh zone of the lake where trees have spread lakeward from the original plantings. *Melaleuca* infestations in the marsh zone typically consist of outlier trees and heads of varying ages. Surveys indicate that over a quarter of the 100,000 acre marsh zone is populated, to some degree, with *Melaleuca* (Figure 23), although the coverage of live trees has been greatly reduced by management programs.

Torpedo grass is an exotic perennial grass, that has become a significant weed problem throughout much of Lake Okeechobee's marsh zone. Torpedo grass is thought to be native to the Europe, but was found in Australia, India, and Africa in the mid-1800s. In Florida, the first reported occurrence of torpedo grass was in the lower Kissimmee River valley during the 1920s. Torpedo grass gained popularity in South Florida because of its cattle grazing value and by 1950 (Hodges and Jones

Figure 23. Geographic Information Systems map showing coverage of live and dead *Melaleuca* in a portion of the Lake Okeechobee marsh zone during 1994.

1950) had been planted in nearly every southern Florida county. It is believed to have been introduced into Lake Okeechobee during the 1940s and until the 1970s, when permits were issued allowing ranchers to graze cattle on the torpedo grass flats within the marsh zone. Torpedo grass now has invaded nearly 2,500 acres of the lake's marsh zone and is continuing to invade new areas adding further stress to the ecosystem. The plant occurs primarily in the northwestern region of the marsh zone, and around the perimeter of Moonshine Bay, just to the south of Fisheating Bay.

D1. Quantifying the Spatial Distribution of Exotic Plants

The lake's marsh zone was photographed with color infrared photography in 1994. Vegetation coverage data have been interpreted from these photographs and entered into a GIS database. These data include the presence, location, and aerial coverage of native and exotic marsh vegetation assemblages, and for *Melaleuca*, which has been targeted in extensive eradication programs (see below), tree condition (live versus dead) and tree density have been included as well. Additional recurrent remote sensing projects designed to identify and quantify vegetation species composition and aerial coverage within the lake's marsh zone will be required over the next ten years to enable SFWMD staff to document the efficacy of the SFWMD's vegetation management efforts, evaluate successional change in both native and exotic macrophyte communities following the removal of exotic vegetation, and to evaluate changes in marsh plant communities exposed to various hydroperiods.

D2. SFWMD Programs for Control of Exotic Plants

Floating weed control-Water hyacinth and water lettuce have rapid growth rates that allow populations of these plants to double every few weeks under ideal conditions. These two plants have covered thousands of acres of the open water and marsh zones of Lake Okeechobee. Until consistent management efforts began in the 1970s, they frequently completely overtook entire portions of the lake. For instance, the southern rim canal repeatedly filled with dense jams that would support cautious pedestrians.

The ongoing control program aims to check their uncontrolled growth before severe damage is dealt to native plants and wildlife and human uses of the lake. This active management program relies upon frequent herbicide applications to meet maintenance goals of a lake 99%-free of floating weeds. This treatment scheme has reduced plant populations to much lower average levels, and, as a result, much less herbicide is used when compared to amounts needed to control weed populations growing out-of-control. Federal funding has consistently been available through the Corps of Engineers "Removal of Aquatic Growth" (RAG) program. This fund has reimbursed all SFWMD aquatic plant control costs in an annual amount averaging about $800,000 for the past ten years.

Mechanical harvesting vessels and on-shore draglines are frequently used to

remove floating weeds from navigation channels and water control structures. Physical methods are always used within one-half mile of active drinking water intakes.

Over the past twenty years, the U.S. Department of Agriculture (USDA) has released several insects in Florida that specifically feed only on water hyacinth or water lettuce. These insects have established self-sustaining populations in the region, but they have not exerted biological control to a degree that would curtail other control methods.

Submersed Weed Control-Hydrilla is a submersed invasive exotic plant, has completely overtaken many waterbodies throughout the world. A lake dominated by *Hydrilla* suffers drastically as nutrients and gas exchanges are radically altered, critical open water fisheries and wildlife habitats are overwhelmed, and navigation and human uses are lost. In Florida, *Hydrilla*'s first report was in Tampa in the early 1960s as aquarium plant growers cultured it in uncontrolled canals. Since then, boating has been the primary means for spreading it to new systems. Its spread has been contained in some lakes, primarily smaller water bodies with single boat ramps and no other navigable connections. Much of Lake Okeechobee, and most of its tributaries, have had *Hydrilla* since the early 1980s. However, only minimal *Hydrilla* control efforts have been mounted through the years, mainly in primary access areas. Funds have never been available to support more control work.

Herbicide treatments and mechanical removal/harvesting methods have attacked *Hydrilla* growth that threatened main navigation channels and water control structure operations. Other areas have had "acceptable" levels of *Hydrilla* such that alternate navigation routes and fish and wildlife utilization areas were available. Wind and wave action seem to have prevented its overtaking the central body of the lake. Also, rapid and wide-ranging water level fluctuations and prolonged very high water levels (above 17 ft.) have repeatedly uprooted or caused its decline in several areas including Cody's Cove, Fisheating Bay, and the southern lake between Ritta and Torry Islands. The USDA has also established several Hydrilla-specific insect populations in Florida. However, these insects have not exerted significant *Hydrilla* control to date.

*Melaleuca Control Program-*On July 21, 1993, representatives of several governmental agencies met to discuss *Melaleuca* control on Lake Okeechobee. Their initial goal was to unify agency efforts for controlling *Melaleuca* on the lake. The group felt it necessary to meet on a routine basis and decided to officially call themselves the Lake Okeechobee *Melaleuca* Advisory Committee. The committee is composed of government agencies including the FDEP, FGFWFC, Florida Division of Forestry, USFWS, USACE and the SFWMD. The committee members serve in an advisory capacity for their respective agencies, providing multi-disciplinary technical and scientific data from which the *Melaleuca* management strategy, methodology, and research planning and operations efforts evolve. From the outset, the committee

has aimed to coordinate the *Melaleuca* management program with other resource management efforts on Lake Okeechobee. With the development of this integrated management plan, the common goal for the elimination of *Melaleuca* from Lake Okeechobee may be achieved.

The Lake Okeechobee *Melaleuca* control project involves several phases. Phase Ia includes the initial elimination of seed-bearing trees and seedlings in the outer-marsh zone of the lake, and on the USACE levee right-of-ways. Phase Ib focuses on the control of large, monoculture stands. Herbicidal control is the primary tool used for mature *Melaleuca* trees in Phase I, although the use of mechanical control coupled with herbicide applications is being investigated.   Selection of particular combinations of herbicide and application methods depends on the condition of the site. Phase II involves follow-up treatment: finding any missed areas and controlling seedlings resulting from Phase I treatments. Phase II control methods include hand-pulling or prescribed burning for the control of seedlings, and herbicidal control of mature trees.   Phase III involves surveillance and inspection to monitor the effectiveness of the control program. Work during this phase also focuses on the long-term management of the area with the eventual introduction of biocontrol agents.

In August, 1993, SFWMD began Phase I treatment of *Melaleuca* trees in the outer marsh zone of the lake. Crews are transported to the work site by airboat. Mature trees are girdled and treated with herbicide ("hack and squirt"). Smaller trees and seedlings are pulled and stacked in large piles to prevent regrowth. To date, a total of 3.8 million trees have been treated and 7.1 million *Melaleuca* seedlings have been hand-pulled within a 20,000 acre section of the 100,000 acre marsh zone. In 1994, the SFWMD conducted two large-scale aerial treatments at Lake Okeechobee. Approximately 260 acres of *Melaleuca* monoculture were aerially treated along the levee between Buckhead Ridge and Indian Prairie Canal. Over 1000 acres of monoculture were treated in the Moore Haven area, west of the Moore Haven Cut.

An integration of all available methods will be required to effectively eliminate this exotic pest-plant from Lake Okeechobee.   These management techniques include: biological, herbicidal, mechanical and physical methods. Biological control agents are not yet available for the management of seedling trees. Physical controls, such as fire and flooding, are not yet completely understood nor easily managed, and mechanical controls have, for the most part, included only manual removal of seedlings.   At this time, herbicides provide the most cost-effective method for controlling *Melaleuca* at Lake Okeechobee. Outlier trees and moderately infested areas are treated manually using a modified hack-and-squirt technique.   Aerial herbicide applications provide an effective control strategy for the large, monospecific *Melaleuca* forests concentrated just lakeward of the levee. These stands are so expansive that manual control would ultimately become too labor intensive, and would not remain a cost effective control method. The development and use of a safe and effective aerial application for *Melaleuca* control is critical to the Lake Okeechobee project.

Miscellaneous Aquatic Plant Management-Great interest has surfaced in recent years to control other plants, both native and non-native, which have established nuisance levels of growth. Cattails (*Typha* spp.), primrose willows (*Ludwigia* spp.), nutsedge (*Cyperus odoratus*), and pennyworts (*Hydrocotle* spp.) are among the native plants which form mixed assemblages of floating mats which overtake valued shallow water areas and navigation channels. Also, cattails have formed dense bands along the western littoral edge of the lake. These stands limit westward fish movement and may also prevent water exchange. Funding has not been available for more than very limited control of these plant growth problems, mainly to restore navigation.

D3. USACE *Melaleuca* Removal and Management Program

The USACE has developed a multifaceted *Melaleuca* management plan for FY95 and FY96. Plans call for the USACE's South Florida Operations Office to continue mechanical removal of *Melaleuca* from its right-of-way. This includes trees located adjacent to the Herbert Hoover Dike and those located on the tree islands lakeside of the rim canal. The USACE is in the process of conducting an Environmental Assessment (EA) to determine potential environmental effects of planned *Melaleuca* operations on the C&SF Project. The EA will be coordinated through appropriate agencies for review and comment. Plans will be coordinated with the USDA for release and monitoring of a candidate biological control agent currently in quarantine at the USDA lab in Gainesville, Florida. Areas for release will be determined at a later date. The USACE also is in the process of negotiating with an architectural firm for the design of a *Melaleuca* quarantine facility.

D4. Quantifying Optimal Control Strategies

In the case of torpedo grass, there are no ongoing control programs, and the focus is on experimental research projects designed to identify the most effective control strategies. The rapid expansion of torpedo grass is due in part to an aggressive growth habit that is supported by extensive rhizomes which can occupy 70 to 90 percent of the plant's total biomass. Two separate research studies designed to develop control techniques that can be used to manage torpedo grass were begun in 1995. They involve controlled applications of herbicides to replicated plots in the lake's marsh zone, and assessment of plant responses. Research using glyphosate herbicides is being conducted by the University of Florida and will continue through 1997. A management strategy for torpedo grass in wetland environments has been difficult because there are only a limited number of herbicides registered for use in aquatic habitats. A systemic herbicide is required for controlling torpedo grass because the rhizome must be killed. Glyphosate, trade name Rodeo[TM], is one of the few systemic herbicides registered for use in aquatics. One current research project includes evaluation of: (1) multiple treatment rates of glyphosate, multiple treatment frequencies, and the timing of treatments (seasonal effects); (2) importance of the percent of leaf material above the water line at the time of treatment (e.g., the more leaf surface area exposed to the herbicide the greater the rate of herbicide uptake); (3)

herbicide adjuvants to determine rain-fast characteristics; and, (4) plant growth regulators, to determine if rhizome node dormancy can be broken prior to a glyphosate treatment to increase glyphosate uptake into the rhizome. Research using the herbicides Imazapyr (Arsenal[TM]) and Fluridone (Sonar[TM]) is also being conducted by SFWMD staff.

E. QUANTIFYING ECOLOGICAL TRENDS

Given the continued human impacts on Lake Okeechobee, and our attempts to reverse those impacts through carefully-planned management actions, it is necessary to periodically assess the status of the ecosystem. Although there are ongoing programs to monitor certain ecological components, including phyto- and zooplankton (SFWMD), marsh zone vegetation, including GIS mapping of exotic and native plant communities (SFWMD), benthic macroinvertebrates and selected fish species (FGFWFC), there has not been an organized program to quantify overall ecosystem health. SFWMD staff recently developed a general plan (Havens and Rosen 1996) that could be used as a framework for an integrated, multi-agency sampling effort. The ultimate goal is a readily-accessible electronic data repository containing historic records of key ecological attributes that collectively describe ecosystem health. SFWMD and FGFWFC staff have discussed this goal, and already have begun to integrate some of the biological sampling efforts.

According to the ecological monitoring plan, measured attributes should reflect the status of three general ecosystem properties: (1) *spatial extent and standing stock* - the areal extent of lake features such as algal blooms, exotic plant populations, and benthic sediment types, as well as the standing stocks of biotic features such as commercial fish species, and chlorophyll a concentration; (2) *biological diversity* - the taxonomic or functional diversity of biological communities, including algae, vascular plants, and animals; and, (3) *ecological function* - the rates of key ecological processes, especially those related to bioenergetics and nutrient recycling. A list of indicators considered to be of highest priority (judged by their empirically-demonstrated sensitivity to known human impacts on the lake) is provided in Table 12, along with proposed sampling frequencies, determined from previous scientific studies. Under this scheme, one may derive a set of readily-measured ecological metrics (e.g., the ratio of diatoms to blue-green algae) for each indicator (e.g., phytoplankton), and then compare present status of metrics with some established restoration targets. In the case of the ratio of diatoms to blue-green algae, for example, current values are near 0.5, while historic data indicate that a ratio of >1.3 would be more typical for the natural lake ecosystem. One of the significant findings of Havens and Rosen (1996) was the lack of necessary information to establish restoration targets and/or current status for most ecological metrics. Establishing that information should be a focus of future research.

Table 12. Ecological values and indicators, and suggested sampling scheme based on documented spatial and temporal variation in each indicator. References are to the most recently published information (from Havens and Rosen 1996).

Values and Indicators	Sampling Design	Frequency	Reference
I. Spatial Extent			
Marsh Macrophytes	remote sensing	3 years	Richardson & Harris (1995)
Fish	multiple limnetic & marsh sites	yearly	Bull et al. (1995)
Nutrients	multiple limnetic & marsh sites	< monthly	Phlips et al. (1995)
Algal blooms	multiple limnetic	< monthly	Havens et al. (1995a)
Sediments	multiple limnetic sites	10 years	Mehta (1993)
II. Biological Diversity			
Phytoplankton	multiple limnetic sites	monthly	Cichra et al. (1995)
Attached Algae	multiple marsh & benthic sites	quarterly	Steinman et al. (1997)
Benthic Animals	multiple limnetic sites	quarterly	Warren *et al.* (1995)
Fish	multiple limnetic & marsh sites	yearly	Bull *et al.* (1995)
III. Ecological Function			
Algal Productivity	multiple limnetic & marsh sites	monthly	no recent data
Limiting Factors	multiple limnetic & marsh sites	monthly	Aldridge *et al.* (1995)
Sediment Phosphorus Exchange	multiple limnetic sites	5 years	Olila & Reddy(1993)

F. LAKE OKEECHOBEE'S ROLE IN THE REGIONAL ECOSYSTEM

Lake Okeechobee must be considered in the context of the regional aquatic ecosystem of South Florida.   Many of the natural connections have been lost and unnatural ones built, such as the dikes, canals, and structures of the C&SF Project. The lake presently is interconnected with the Kissimmee River, the Caloosahatchee and St. Lucie estuaries, and through the canal system to the Florida Everglades. Water quality, quantity and the timing of water delivery is affected by Lake Okeechobee, which has direct and indirect effects on these ecosystems. Many species of wildlife utilize resources on a regional scale, and Lake Okeechobee is a major resource for these populations (e.g., wading birds), including rare, threatened or endangered species.

F1. Protection and Management of Rare, Threatened and Endangered Species

The lake and its associated wetlands provide habitat for a myriad of plants and animals, including a number of rare and endangered species (e.g., the wood stork, snail kite, West Indian manatee and the Okeechobee gourd, Table 13). Migratory birds and waterfowl utilize the marsh zone and adjacent wetlands as a major resting area along the Atlantic flyway.   Protection of these species and restoration or enhancement of their habitat is an important environmental resource management issue.

MANATEE PROTECTION PLAN

In 1994, 16 manatees were killed in C&SF project structures. This is the highest number of fatalities recorded in a single year, and approximately four times the annual average over the past 20 years. Twelve of the 16 fatalities occurred in Lake Okeechobee or Okeechobee Waterway structures. This large number of fatalities is believed to be largely due to the unprecedented operation of these structures during the exceedingly wet 1994 season.

Manatee mortality occurs in both spillgates and navigation lock structures. Relative to spillgates, it may be further subdivided into injury resulting from entrapment beneath gates in tidal conditions (i.e., Dade County), or mortality associated with elevated spillgates having a significant difference in headwater and tailwater conditions (i.e., Okeechobee Waterway).   Each of these three types of mortality must be addressed in a different manner.

SFWMD efforts have previously focused upon eliminating mortality associated with tidal spillgates. In addition to modifying gate opening ranges and frequency, a prototype sensor switch system has been developed and installed at two Dade County structures (S-27 and S-29). This system consists of a series of plunger switches along the bottom of the water control gate which, when depressed, terminate the gate closure and initiate a reopening. The system is analogous to the protective devices

TABLE 13. Threatened, Endangered, and Species of Special Concern by County.

Species	County	Species Designation by Agency		
		FGFC	FDA	USFWS
Mammals				
Florida Black Bear *Ursus americanus floridanus*	G, H, He, Os, P, PB	T		C2
Florida Long Tailed Weasel *Mustela frenata peninsular*	G, He, Ok, Os, P			C2
Florida Mouse *Podomys floridanus*	H, M, Os, P, PB, S	SSC		C2
Florida Panther *Felis concolor coryi*	G, H, He, M, PB	E		E
Mangrove Fox Squirrel *Sciurus niger avicennia*	He	T		C2
Round-tailed Muskrat *Neofiber alleni*	G, H, He, Ok, Os, P, PB			C2
Sherman's fox squirrel *Sciurus niger shermani*	G, H, M, Ok, Os, P, PB, S	SSC		C2
Southeastern Beach Mouse *Permyscus polionotus niveiventris*	S	T		T
Southeastern Big Eared Bat *Plecotus rafinesquii*	H, Ok, Os, P			C2
Southeastern Shrew *Sorex longirostris longirostris*	H, Os, P	SSC		C2
West Indian Manatee *Trichechus manatus*	G, He, Ok, PB	E		E
Birds				
American Oystercatcher *Haematopus palliatus*	M, PB, S	SSC		
Bachman's Sparrow *Aimophila aestivalis*	G, H, He, Ok, Os, P			C2
Bald Eagle *Haliaeets leucocephalus*	G, H, M, Ok, Os, P, PB, S	T		E
Black Skimmer *Rynchops niger*	M, PB, S	SSC		
Brown Pelican *Pelecanus occidentalis*	M, PB, S	SSC		
Crested Caracara *Polyborus plancus*	G, H, He, M, Ok, Os, P, PB, S	T		T
Florida Grasshopper Sparrow *Ammodromus savannarum floridanus*	G, H, He, Ok, P	E		E
Florida Sandhill Crane *Grus canadensis pratensis*	G, H, He, M, Ok, Os, P, PB, S	T		
Florida Scrub Jay *Aphelocoma coerolescens coerulescens*	G, H, M, Ok, Os, P, PB, S	T		T
Least Tern *Sterna antillarum*	H, M, PB, S	T		
Limpkin *Aramus guarauna*	G, H, He, M, Ok, Os, P, PB, S	SSC		
Little Blue Heron *Egretta caerulea*	G, H, He, M, Ok, Os, P, PB, S	SSC		

Species	County	Species Designation by Agency		
		FGFC	FDA	USFWS
Peregrine Falcon *Falco peregrinus*	G, H, He, M, Ok, Or, Os, P, PB, S	E		T
Piping Plover *Charadrius melodus*	M, PB, S	T		T
Red Cockaded Woodpecker *Picoides borealis*	G, H, M, Os, P, PB	T		E
Roseate Spoonbill *Ajaia ajaia*	M, S	SSC		
Snail Kite *Rostrhamus sociabilis plumbeus*	G, He, PB, S	E		E
Snowy Egret *Egretta thula*	G, H, He, M, Ok, Os, P, PB, S	SSC		
Southeastern American Kestrel *Falco sparverius paulus*	G, H, He, Ok, M, Os, P, PB, S	T		C2
Tricolor Heron *Egretta tricolor*	G, H, He, M, Ok, Os, P, PB, S	SSC		
Wood Stork *Mycteria americana*	G, H, He, M, Ok, Os, P, PB, S	E		E
Reptiles American Alligator *Alligator mississippiensis*	G, H, He, M, Ok, Os, P, PB, S	SSC		T(S/A)
Atlantic Green Turtle *Chelonia mydas mydas*	M, PB, S	E		E
Atlantic Hawksbill Turtle *Eretmochelys imbricata imbricata*	M, PB	E		E
Atlantic Loggerhead Turtle *Caretta caretta caretta*	M, PB, S	T		T
Blue-tailed Mole Skink *Eumeces egregius lividus*	H, P	T		T
Eastern Indigo Snake *Drymarchon corais couperi*	G, H, He, M, Ok, Os, P, PB, S	T		T
Florida Pine Snake *Pituophis melandeucus mugitus*	H, P, PB, S	SSC		C2
Florida Scrub Lizard *Scelaporus woodi*	H, Os, P, PB			C2
Gopher Tortoise *Gopherus polyphemus*	G, H, He, Ok, M, Os, P, PB, S	SSC		C2
Leatherback Turtle *Dermochelys coriacea*	M, PB, S	E		E
Sand Skink *Neoseps reynoldsi*	H, Os, P	T		T
Short Tailed Snake *Stilosoma extenuatum*	H, P	T		C2
Suwannee Cooter *Pseudemys concinna suwanniensis*	P	SSC		
Amphibians Gopher Frog *Rana areolata*	H, G, Os, P, PB	SSC		C2

Species	County	Species Designation by Agency		
		FGFC	FDA	USFWS
Plants				
Ashe's Savory *Calamintha ashei*	H, P		T	C1
Auricled Spleenwort *Asplenium auritum*	H		E	
Avon Park Rabbit bells *Crotalaria avonensis*	H		E	
Banded Wild-pine *Tillandsia flexuosa*	H, He, M, PB		T	
Beach Star *Remirea maritima*	M, PB, S	T	E	
Britton's Bear Grass *Nolina brittoniana*	H, Os, P		E	E
Burrowing Four O'Clock *Okenia hypogaea*	M, PB		E	
Carter's Large-flowered Flax *Linum carteri var smallii*	M, PB		E	
Carter's Warea *Warea carteri*	H, P		E	E
Chaffseed *Schwalbea americana*	H		E	E
Clasping Warea *Warea amplexifolia*	Os, P		E	E
Craighead's Nodding-Caps *Triphora craigheadii*	H		T	C2
Curtiss' Milkweed *Asclepias curtissii*	H, M, Os, P, PB, S		E	
Cutthroat Grass *Panicum abscissum*	H, He, Os, P		T	C2
Dollar Orchid *Encyclia boothiana var erythroniodes*	M		E	
Edison's Ascyrum *Hypericum edisonianum*	H, G		T	C2
Fall Flowering Ixia *Nemastylis floridana*	Ok, Os, PB		E	C2
Florida Bonamia *Bonamia grandiflora*	H, Os, P		E	T
Florida Gay Feather *Liatris ohlingerae*	H, P		E	E
Florida Jujube *Ziziphus celata*	H, P		E	E
Florida Keys Ladies' Tresses *Spiranthes polyantha*	M		E	
Florida Lantana *Lantana depressa*	H, He, P, PB			C2
Fragrant Prickly Apple *Cereus eriophorus var fragrans*	S		E	
Gulf Spikemass *Selaginella ludoviciana*	H, D		T	
Garrett's Scrub Balm	H		E	

Species	County	Species Designation by Agency		
		FGFC	FDA	USFWS
Dicerandra christmanii				
Hairy Jointweed *Polygonella basiramia*	H		E	E
Hand Fern *Ophioglossum palmatum*	M, P, PB, S		T	
Hartwrightia *Hartwrightia floridana*	H, P		T	C2
Highlands Scrub Hypericum *Hypericum cumulicola*	H, P		E	E
Incised Groove-Bur *Agrimonia incisa*	P			C2
Large Flowered Rosemary *Conradina grandiflora*	M, Os, PB, S		E	C2
Lewton's Polygala *Polygala lewtonii*	H, Os, P		E	E
Lowland Loosestrife *Lythrum flagellare*	G, He, Ok, Os			C2
Meadow Spikemoss *Selaginella apoda*	He, Os, P		T	
Night Scented Orchid *Epidendrum nocturnum*	M, Ok, PB		T	
Nodding Pinweed *Lechea cernua*	H, M, Os, P, PB		E	C2
Okeechobee Gourd *Cucurbita okeechobeensis*	G, He, PB		E	E
Paper-Like Nail-Wort *Paronychia chartacca*	P		E	T
Perforate Cladonia (lichen) *Cladonia perforata*	H			E
Piedmont Jointgrass *Coelorachis tuberculosa*	H			C2
Piedmont Water-Milfoil *Myriophyllum laxum*	Os			C2
Pigeon Wing *Clitoria fragrans*	H		T	T
Pigmy Fringe-Tree *Chionanthus pygmaeus*	H, Os, P		E	E
Pine Pinweed *Lechea divaricata*	H, M, PB		E	C2
Rain Lily *Zephyranthes simpsonii*	G, H, He, M, Ok, Os, P, PB		E	
Redberry Ironwood *Eugenia confusa*	M		T	
Sand-Dune Spurge *Chamaesyce cumulicola*	H, PB			C2
Scrub Bluestem *Schizachyrium niveum*	H, P			C1
Scrub Buckwheat *Eriogonum longifolium var gnaphalifolium*	H, Os, P		T	T

Species	County	Species Designation by Agency		
		FGFC	FDA	USFWS
Scrub Lupine *Lupinus aridorum*	P		E	E
Scrub Mint *Dicerandra frutescens*	H, P		E	E
Scrub Plum *Prunus geniculata*	P		E	E
Short-Leaved Rosemary *Conradina brevifoli*a	H, P		E	
Slender-Leaved Dragon Head *Physostegia leptophylla*	P			
Small's Jointweed *Polygonella myriophylla*	H, Os, P		E	
Southern Maidenhair Fern *Adiantum capillus-veneris*	H, M		T	
Southern Red-Lily *Lilium catesbaei*	H, M, Ok, Os, P, PB, S		T	
Spoon-Leaved Sundew *Drosera intermedia*	H		T	
Spotless-Petaled Balm *Diceranda immaculata*	S		E	
Star Anise *Illicium parviflorum*	P		T	C2
Terrestrial Peperomia (Pepper) *Peperomia humilis*	M, S		E	
Vanilla *Vanilla mexicana*	M		T	
Wedge-Leaved Button-Snakeroot *Eryngium cuneifolium*	H, P		E	E
Wild Coco *Pteroglossaspis ecristata*	H, M		T	C2
Yellow Fringeless Orchid *Platanthera integra*	Os		T	

<u>County:</u>   G = Glades; H = Highlands; He = Hendry; M = Martin; Ok = Okeechobee; Os = Osceola; P = Polk; PB = Palm Beach; S = St. Lucie.

<u>Species Designations:</u> E = Endangered; T = Threatened; SSC = Species of Special Concern. C1 = A candidate for federal listing for which there is enough substantial information on biological vulnerability and threats to justify listing. C2 = A candidate for federal listing with some evidence of vulnerability, but for which not enough information exists to justify listing. C1 and C2 species are not federally protected under the Endangered Species Act, but the USFWS "encourages their consideration in environmental planning" (US Code of Federal Regulations Vol. 55, No. 35, pp. 6184-6229).

<u>Agencies:</u> FGFC = Florida Game and Fresh Water Fish Commission - Jurisdiction over Florida's animals (vertebrates and invertebrates); FDA = Florida Department of Agriculture and Consumer Services - Jurisdiction over Florida's plants; USFWS = United States Fish and Wildlife Service - Jurisdiction over nation's plants and animals.

<u>Source:</u> The Nature Conservancy, 1990 and Florida Game and Fresh Water Fish Commission, 1993.

utilized in elevator doors.

While the conflict with tidal spillgates may be addressed by implementing modifications to insure safe passage through the structure gate, the elevated spillgates pose another dilemma in that manatees may be injured when dropping from the upper to lower water levels at these structures. The only alternative is to design barrier systems which prevent manatees from passing through these gates. This presents a serious design problem in that the barrier must exclude manatees and yet not become clogged with aquatic weeds and impair flood control. In 1994 the USACE installed prototype screening at the Ortona spillgates and is currently investigating other exclusion designs. The USACE Waterway Experiment Station is also investigating the potential for using SONAR systems to locate manatees near the water control structure. This would allow immediate operational changes at the structures to further protect manatees.

The USACE installed and tested a hydraulic tube switch at the Port Myaca lock. It consisted of a vertical soft-walled tube mounted on the gate edge designed to be compressed by any object between the gates. The USACE found problems in maintaining the low-pressure tolerance in the system and had difficulty mounting the tubes on the gate face. Another devise was being tested simultaneously by the SFWMD. This new system, a piezo-electric film strip, was installed on a Dade County floodgate and appears successful. It is now being installed at other floodgates. Based upon the piezo-electric application at floodgates, the USACE is currently contracting with the Harbor Branch Oceanographic Institute (who developed the floodgate prototype) to install a prototype test system on the St. Lucie Lock. This system may allow sensing the presence of a manatee without it actually touching anything. This is projected to be installed in late 1997.

F2. Kissimmee River Restoration Project

An important component of the lake's regional ecosystem is the Kissimmee River water inflow to Lake Okeechobee, and as such, it has a significant impact on the lake ecosystem. In the 1960s, much of the ecological integrity of the river ecosystem was lost when the USACE dredged a large section of the river channel with the goal of flood protection. Almost immediately, it was recognized that the anticipated benefits of the project were not realized, and that an extensive natural wildlife habitat had been destroyed. Furthermore, severe anoxia developed in the deep artificial river channel, and large fish kills occurred (Toth 1993).

The state and federal governments have entered into a partnership to implement the Kissimmee River restoration project (Koebel 1995) with the goal of restoring ecological integrity in the Kissimmee River ecosystem. The project includes: (1) continuous backfilling of 22 miles of the C-38 canal and acquisition of the adjacent floodplain; (2) removal of two water control structures (S65-B and S65-C), degrading levees located in the floodplain, constructing a protection levee across the Istokpoga

Canal, and reconstructing approximately 9 miles of river channel; (3) expanding canals connecting lakes Kissimmee, Hatchineha, and Cypress, and improving the structure at the outlet of Lake Kissimmee (S65); and, (4) land acquisition to allow additional water storage capacity in these three lakes plus Tiger Lake. While this component provides the critical flows to the river/floodplain, water elevations also will be allowed to fluctuate more naturally in lakes Kissimmee, Hatchineha, and Cypress and will enhance the marsh zones around these lakes reestablishing fish and wildlife habitat.

A final component of the restoration program is a comprehensive ecological evaluation (Dahm *et al.* 1995), designed to quantify the extent to which the project meets established restoration goals, and to provide for continuous, scientifically-informed modification (adaptive management) of the reconstruction efforts. The evaluation program will have an ecosystem perspective, involving a suite of prioritized ecological indicators that can be used to track response and recovery of multiple ecosystem components, including physical and chemical habitat parameters, such as hydrology and water quality, and biological attributes like vegetation, fish, wading birds and waterfowl. The evaluation program will consider both the direction and extent of recovery of these indicators, from an established baseline (i.e., existing) condition to a historically-based reference (i.e., expected) condition.

F3. Environmental Impacts on Estuaries

The Caloosahatchee and St. Lucie estuaries, located on the west and east coasts of Florida, respectively face three major problems that are linked, in part, to Lake Okeechobee: (1) disruption of the natural magnitude and timing of freshwater discharges; (2) increasing input of nutrients and other materials of concern; and   (3) loss of critical estuarine habitats and species. These problems are not mutually exclusive and thus require an integrated problem solving approach.   For example, alteration in the watershed and/or lake regulation schedule may increase freshwater discharge, which directly impacts the biota within the affected estuary. Increased inflow also may increase nutrient loading. Nutrient enrichment of estuarine systems may cause increased epiphyte and phytoplankton growth, which reduces available light and results in the decline of submerged macrophyte populations. This is just one of many possible scenarios and problems confronting the Caloosahatchee Estuary (CE) and St. Lucie Estuary (SLE). In addition, the degree of influence that the lake and watersheds each exhibit is in the process of being quantified and must be determined in order to understand and manage nutrient enrichment of these ecosystems.

The following management strategies are based on the Valued Ecosystem Component approach developed by the USEPA (1987) as part of its National Estuary Program. Valued Ecosystem Components (VEC) consist of key species or groups of species that sustain the ecological structure and function of prominent estuarine communities by providing food, living space, refugia, and foraging sites for other

estuarine-dependent species. Examples include seagrasses and oysters. The following strategies provide a suitable salinity and water quality environment for these key estuarine species. A suitable environment will be determined by employing a combination of research approaches that include field monitoring, experimental and process-oriented research, and ecological modeling. These methods will be integrated to establish relationships between salinity, nutrients, light, and estuarine biota so that predictions about impacts of modified water delivery can be made with the minimum practical level of uncertainty.

F3a. Quantifying Impacts of Fresh Water Discharges from the Lake

Establishing a suitable salinity environment is the most basic prerequisite for promoting key estuarine biota. Salinity influences productivity, population distribution, predator-prey relationships, and composition of communities in the estuary. Both basin runoff patterns and releases of freshwater from the lake can cause severe salinity fluctuations in the Caloosahatchee and St. Lucie Estuaries.

Several SFWMD studies have indicated the negative effects of high discharges and extreme low flows to the St. Lucie Estuary and Caloosahatchee Estuary (IRL SWIM Plan 1994). These studies have shown that prolonged releases, even at modest rates, can transform up to 80% of these estuaries into freshwater habitats within three to four weeks of continuous discharges. At the other extreme, long periods of restricted inflows can adversely impact low-salinity dependent species.

Therefore, these ecosystems first require the establishment of an optimum distribution of freshwater inflow from the lake and watersheds that protects and enhances VEC. To accomplish this strategy, the effects of freshwater discharges from SFWMD structures (lake-connected and non-lake) on the spatial distribution and temporal fluctuation of salinity within the St. Lucie Estuary and Caloosahatchee Estuary must first be determined. The dependence of salinity on freshwater discharge in these estuaries will be examined both statistically, by analyzing data already collected, and mechanistically through the development of mathematical models, which predict the distribution of salinity as a function of freshwater input. Second, the SFWMD needs to understand how variation in salinity influences the abundance and species composition of biological communities and the processing of material (e.g., nutrients) in the systems. The SFWMD will use analysis of existing survey data, field manipulations, and mesocosm experiments to determine the tolerance limits of the key species. In this process, the SFWMD will seek to distinguish between sources of freshwater in order to determine how regulatory discharges from the lake vs. basin runoff may differentially affect salinity and biological communities in the estuaries. Third, the separate influence of the watersheds and lake on the Caloosahatchee Estuary and St. Lucie Estuary must be determined to establish an optimum water delivery strategy.

Caloosahatchee Estuary. There is little information that directly addresses the

impacts of water management on the biota in the CE. Therefore, SFWMD research is needed to define the optimum flow distribution. Water quality and biological (zooplankton, phytoplankton, ichthyoplankton, benthic macrofauna, submerged aquatic vegetation) data were collected monthly and during lake pulse releases from 1985-1989. The wet season of 1994 and most of 1995 was wetter than normal, necessitating constant (4,500 cfs) discharges from the lake. In response to these high discharges (not encountered consistently during 1986-89), a monitoring program similar to the one carried out between 1986-89 was re-initiated to capture the influence of these high inflows. Comparison of the two sampling periods (1986-89 and 1994-95) and the development of statistical relationships between freshwater inflow/water quality and the structure of important biological communities will allow the SFWMD to define potential effects on water quality and biota that occur at various inflow volumes.

The first estimates of the optimum fresh water inflow range were provided by Haunert and Chamberlain (1994) as part of an evaluation of alternative lake schedules. Criteria for comparing the schedules were developed based on amount of flow range exceedence. Additional analysis of the 1986-89 and 1994-95 data, coupled with the results of the steady state salinity model, aerial seagrass coverage and their salinity tolerances (literature values), and a preliminary optimization model of watershed flow and retention, provided a better estimate of the optimum fresh water inflow distribution (Chamberlain *et al.* 1995). The preliminary estimates of optimum inflow distribution consist of inflows between 300 and 2,800 cfs with a peak around 800 and an allowable exceedence tolerance at the low and high flow ends to provide for natural system variation.

St. Lucie Estuary. Similar management issues are being considered in the St. Lucie Estuary system. The potential of the St. Lucie Estuary (SLE) to function as a productive ecosystem has been adversely affected by land development and water management practices within and outside its watershed. Increased drainage and water usage have reduced groundwater levels, changed surface water runoff characteristics, and increased sediment load to the estuary. From a long-term perspective, the quantity and frequency of discharges to the estuary are increased during the wet season and decreased during the dry season. From a short-term perspective, storm water runoff events are of shorter duration, but of higher discharge volumes.

This accelerated introduction of freshwater to the system causes undesirable salinity fluctuations in the estuary. In addition, large unnatural freshwater inflows from Lake Okeechobee occur when regulatory releases are made to lower the lake. These discharges transport large quantities of sediment to the St. Lucie Estuary and dramatically alter the salinity gradient. Biota within the SLE, Indian River Lagoon, and near shore reefs can be negatively affected by these high volume discharges.

The St. Lucie Estuary was the first estuary intensively studied by the SFWMD,

and continues to be crucial to understanding the environmental link between watershed and lake discharges and the response of estuarine water quality and biota. Initial environmental research (Haunert and Startzman 1980, 1985; Haunert 1986) and concurrent development of the St. Lucie Estuary hydrodynamic/salinity model (Morris 1987) assessed the environmental status of finfish, benthos, sediments, and the impacts of large regulatory releases from the lake.

The results of these studies provided preliminary estimates of minimum, maximum, and optimum inflow-salinity ranges (Haunert and Chamberlain 1994). Through these efforts it has been provisionally determined that flows greater than 2,500 cfs do not occur naturally in the SLE. Flows exceeding 2,500 cfs transform a large portion of the estuary to freshwater.   Therefore, estuarine biota that are adapted to a specific range of salinity and flow limits are stressed and often perish under high volume releases from the lake and/or watershed. As an example, oysters beds represent an important VEC as habitat for numerous estuarine species and as water filters which can significantly improve water quality in the estuary. Figure 24 depicts the anticipated distribution of oysters to be between 5 and 11 miles downstream of S-80 in the St. Lucie Estuary under natural flow conditions unaltered by high regulatory releases. However, due to salinity modifications caused by past high volume discharges, the actual distribution is limited to a much smaller area, approximately about 8-11 miles downstream of S-80.

As in the CE, in order to determine the final optimum inflow distribution, future research will be required to examine the salinity tolerance of seagrass, oysters and other VEC, as well as fish usage of these habitat makers. This research is contingent on available funding, but if conducted will probably be similar to the on-going and planned studies in the Caloosahatchee Estuary that employ a combination of field and laboratory experiments.

F3b. Impacts of Nutrients and Critical Material Loading

In addition to establishing the appropriate bounds for the quantity of water entering the estuary, the quality of water entering the system also requires attention. This strategy consists of two parts: (1) defining the water quality goals of the estuary and conducting the appropriate research to understand how to attain the goals, and (2) distinguishing the sources of loading and establish loading limits for each source.

Mote Marine Laboratory (MML) proposed a water quality goal for the St. Lucie Estuary that seeks to provide water quality sufficient to support, maintain, and improve VEC within the optimum inflows established via the prior strategy. This water quality goal (of the MML plan) has applicability in the Caloosahatchee Estuary as well.   Associated sub-goals for both systems include: (1) preventing benthic anaerobic conditions by maintaining bottom dissolved oxygen (DO) levels greater than 2 mg/l throughout the estuaries; (2) maintaining sediment oxygen demands that are low enough to achieve this DO sub-goal; (3) providing a minimum of 25% of

Figure 24. Anticipated distribution of oysters in the St. Lucie Estuary. Different salinity conditions exist based on flows at S-80, which receives excess freshwater during regulatory releases from Lake Okeechobee as well as the adjacent watershed during periods of heavy rainfall (Haunert and Chamberlain 1994).

incident light available to a depth of 1 meter; (4) restricting new supplies of sediment to achieve the light sub-goal; (5) maintaining water color levels low enough to achieve the light sub-goal; (6) limiting chlorophyll *a* concentrations to meet the DO and light sub-goals; and, (7) maintaining nutrient supplies to the system (both external and internal loads) low enough to achieve the chlorophyll *a* sub-goal and prevent destructive epiphyte fouling of SAV.

In regard to the Caloosahatchee Estuary system, the FDEP reported that it had reached its nutrient loading limits (DeGrove 1981) based on elevated chlorophyll a and depressed oxygen levels. Waste load allocations were developed as part of this study (DeGrove 1981) for the five most significant point sources between Beautiful Island and Shell Point. Both nitrogen and phosphorus were considered to be the water quality-limiting factors (co-limiting) in the river and that the total discharge limitations for this section of river was 1,225 pounds per day of total nitrogen and 204 pounds of phosphorus. Diversion of S-4 basin water to the Caloosahatchee River and eventually the estuary was proposed to protect and improve water quality within Lake Okeechobee. Although this was never officially undertaken, requirements to reduce back-pumping to the lake during wet conditions have resulted in additional nutrient loading from the S-4 basin to the Caloosahatchee system. In addition, increased agricultural and urban development in the Caloosahatchee basin has probably increased material loading to the estuary. Additional non-point source contributions were evaluated by Baker (1990). It was estimated that S-4 diversion alone would add up to 170 pounds/day of phosphorus and 1,425 pounds/day of nitrogen, effectively doubling the quantity of nutrients entering the estuary if the total S-4 basin loading was diverted. As indicated above, FDEP determined that significant additions of either nitrogen or phosphorus would have an adverse effect and should not be allowed. Significant was defined as greater than 10%. Additional information is needed concerning the actual loading amount, sources, and their fate in order to establish limits for the estuary and basin.

In the St. Lucie Estuary system, there also are signs of nutrient overloading. The estuary experiences large phytoplankton blooms and periods of hypoxia in its bottom waters (Chamberlain and Hayward 1996; Graves and Strom 1992). Data analysis by Chamberlain and Hayward indicated that more stable, lower inflows will improve water quality in the St. Lucie Estuary and help attain the water quality features stated above. These results supported establishing inflows in the range previously defined by Haunert and Chamberlain (1994) in their summary of past research results and Lake Okeechobee regulation schedule evaluation. Chamberlain and Hayward also reported that future basin management efforts must decrease nitrogen and phosphorus loading to the St. Lucie Estuary below the current level associated with the low to moderate inflows in order to: (a) meet the water quality requirements for submerged vegetation and good water quality; and, (b) prevent elevated chlorophyll *a* levels when flows and color are decreased. Chamberlain and Hayward suggested the following reductions: total nitrogen by 25%, total phosphorus loading by at least 50%, and soluble reactive phosphorus by 80%.

The same requirements for future work in the St. Lucie Estuary and watersheds are also needed for the CE, with the exception of statistical analysis of water quality monitoring and historical loading trends. In addition, long-term monitoring should be continued in order to determine if the final loading limits established in the future will result in the desired estuarine benefits.

F3c. Development and Implementation of Water Release Programs

In 1988 the SFWMD developed a pulse release and early release program for the Caloosahatchee Estuary and St. Lucie Estuary that included multiple release options for managing the lake to help avoid the possibility of making large-scale volume releases of fresh water to these estuaries. This program has proven successful and its concept has been part of all subsequent lake schedule proposals. In essence, this concept is useful during above-normal rainfall years, which results in high lake stages. The program consists of a series of three lower stage zones for the early release of a smaller volume of water from the lake to reduce impacts to the Caloosahatchee Estuary and SLE. These early releases are delivered in 10-day sets with daily volumes fluctuating in a fashion that is similar to discharges resulting from a natural storm event. The pulse level volumes and schedule is defined by Hall (1991). The final and formal adoption of this strategy for the lake occurred with adoption of the current Lake regulation schedule, Run 25, in 1994 (see Chapter 5).

Performance criteria for evaluating alternative lake schedules were developed by Haunert and Chamberlain (1994) and require updating as new information regarding optimum inflows becomes available. In order to conduct alternative lake schedule evaluations, simulated estuary regulatory discharges associated with each schedule are related to the impacts on the estuaries. As part of this SFWMD-USACE effort (described above) the SFWMD will provide the findings associated with ongoing studies on the St. Lucie and Caloosahatchee Estuaries to assess the impacts of fresh water discharges to these systems. This information will be used to quantify how different scenarios for water delivery in the C&SF system might impact the estuarine biota.

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